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# Correlating the electrification of volcanic plumes with ashfall textures at Sakurajima Volcano, Japan

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ABSTRACT

Volcanic lightning detection has become a useful resource for monitoring remote, under-instrumented volcanoes. Previous studies have shown that the behavior of volcanic plume electrification responds to changes in the eruptive processes and products. However, there has not yet been a study to quantify the links between ash textures and plume electrification during an actively monitored eruption. In this study, we examine a sequence of vulcanian eruptions from Sakurajima Volcano in Japan to compare ash textural properties (grain size, shape, componentry, and groundmass crystallinity) to plume electrification using a lightning mapping array and other monitoring data. We show that the presence of the continual radio frequency (CRF) signal is more likely to occur during eruptions that produce large seismic amplitudes (>7 μm) and glass-rich volcanic ash with more equant particle shapes. We show that CRF is generated during energetic, impulsive eruptions, where charge buildup is enhanced by secondary fragmentation (milling) as particles travel out of the conduit and into the gas-thrust region of the plume. We show that the CRF signal is influenced by a different electrification process than later volcanic lightning. By using volcanic CRF and lightning to better understand the eruptive event and its products these key observations will help the monitoring community better utilize volcanic electrification as a method for monitoring and understanding ongoing explosive eruptions.



## 1. Introduction

Volcanic lightning has the potential to inform about the physical processes taking place during explosive eruptions, especially at under-monitored volcanoes (Hoblitt, 1994; Bennett et al., 2010; McNutt and Williams, 2010; Cimarelli et al., 2016; Behnke and McNutt, 2014; Van Eaton et al., 2016). Although the operational use of volcanic lightning is in its infancy, a major goal is to determine relationships between electrical activity, eruptive intensity, and ash content, which are important factors for aviation hazards and downwind communities.

Volcanic plumes differ from thunderstorm clouds by the presence of volcanic tephra, their aerosol and gas contents, as well as temperature profiles and methods of convection. The addition of silicate particles adds to the types of charging that contribute to plume electrification. Thunderstorms develop charge primarily through collisional ice-graupel charging. The non-inductive charging of graupel (soft hail) is the most widely accepted theory (MacGorman and Rust, 1998). By comparison, the initially higher temperatures, seen in the near-vent portions of volcanic plumes, inhibit the development of graupel (Van Eaton et al., 2015). Therefore, ice charging mechanisms become important to plume lightning developing in the upper regions of volcanic plumes where sub-freezing temperatures may promote ice formation (Saunders et al., 2006; Williams and McNutt, 2005; Durant et al., 2008; Arason et al., 2011; Schill et al., 2015; Van Eaton et al., 2015, 2016). During initial plume formation, magma fragmentation (fracto-emission) and volcanic ash collisions (triboelectrification) are likely the dominant mechanisms of charging (James et al., 2000, 2008; Forward et al., 2009; Lacks and Sankaran, 2011; Houghton et al., 2013; Mendez-Harper et al., 2015; Mendez Harper and Dufek, 2016). The presence of near-vent plume electrification may hold insights into

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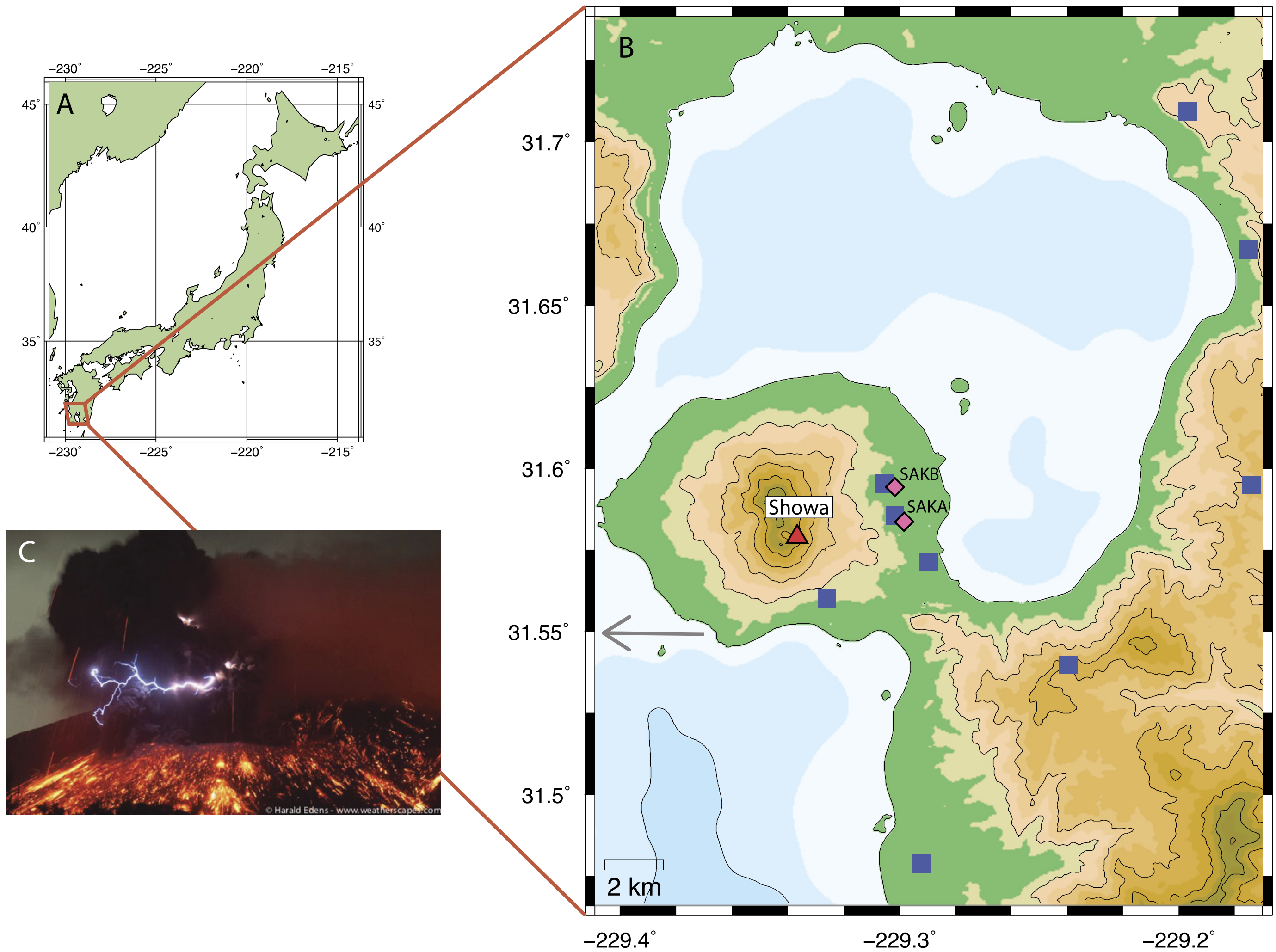


**Fig. 1.** (A) Index map of Japan, with study location boxed in red. (B) Map of Sakurajima Volcano instrument sites. The gray arrow points in the direction of Kagoshima ∼8 km to the west, outside the frame of the map. The red triangle represents the location of Showa crater. The two pink diamonds represent seismic stations, SAKA and SAKB respectively. SAKA is located at the Kurokami lab site where the ash samples were collected. The nine blue squares represent the locations of the individual Lightning Mapping Array sensors. Panel C shows a photograph of volcanic lightning taken by co-author Harald Edens during the field campaign. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

volcanic processes such as fragmentation efficiency and eruptive intensity (Cimarelli et al., 2014; Cashman and Scheu, 2015). There is no prior work in the area of linking ash textural parameters to quantified lightning metrics from an actively monitored eruption.

For this study, volcanic lightning was recorded at Sakurajima Volcano, Japan using the Lightning Mapping Array (LMA) from 29 May–5 June 2015. This follows previous studies of LMA-detected electrical activity at volcanoes such as Eyjafjallajökull (Behnke et al., 2014), Augustine (Thomas et al., 2007, 2010), and Redoubt (Behnke et al., 2013). From these previous investigations, it has become clear that volcanic eruptions produce a unique signal, known as *continual radio frequency* impulses (CRF), that is not present in regular thunderstorms. Our study focuses on determining relationships among: 1) the presence or magnitude of volcanic plume electrification in the form of CRF; 2) quantifiable ash characteristics; and 3) maximum seismic amplitudes for a set of monitored eruptions at Sakurajima during 2015. Correlations among these variables may allow one to use the properties/features of volcanic lightning to invert for the properties of the ejected ash and the eruptive intensity. This could help in the future monitoring of remote volcanoes.

## 2. Background

### 2.1. *Sakurajima Volcano and ash analysis with respect to plume electrification*

Sakurajima Volcano is located within the Aira Caldera in southern Kyushu Japan and is a <13,000 yr old edifice that grew 8 km south of the center of the Aira Caldera (Fig. 1) (Okuno et al., 1997). Historically, Sakurajima has erupted from multiple vents. The southern vents, Minami-dake and Showa are currently active (Okuno et al., 1997). For the past ∼50 yr, Sakurajima has been consistently erupting with small (VEI 2) Vulcanian eruptions producing ash fall that reaches Kagoshima, approximately 8 km west (population ∼600,000).

Vulcanian eruptions, such as those at Sakurajima, typically produce discrete explosions but may also be composed of a series of explosions that may continue for days or years (Clarke et al., 2015). The plumes of Vulcanian eruptions do not typically inject into the stratosphere and are thus lower risk for aviation. However, the study of these common, smaller plumes adds to an understanding of the smaller end-member of explosive volcanism and provides context for the analysis of rarer, large events. Sakurajima's eruptions range from pale, gas-rich puffs to dark, ash-rich jets, which